

# **EXHIBIT O**

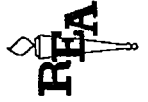
# Modern Microelectronics

BASIC PRINCIPLES

CIRCUIT DESIGN

FABRICATION TECHNOLOGY

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## PREFACE

Historically, the primary object of the original workers in microelectronics was to develop methods for miniaturizing electronic equipment so as to result in technical and economical advantages through reduction of the large bulk and weight that was often associated with electronic installations. As the development program progressed, however, it was found that the methods used to fabricate the miniaturized electronic devices, also yielded two essential features: a very significant increase in the reliability of operation and a sharp reduction in cost. It was soon realized that these two features are of greater importance than the miniaturization characteristic, in promoting widespread acceptability of electronic devices.

Thus, before the advent of microelectronics, the use of complex electronic equipment was limited because of the large amount of continuous servicing that was required to maintain the equipment in operating condition. At the same time, the initial high cost of the equipment also confined its acceptance to relatively few users. Since microelectronic techniques are steadily removing these two obstacles, both industry and government are increasingly relying upon electronic equipment to perform functions previously accomplished through manual means, as well as to perform entirely new functions not possible before. Although microelectronics may still give the impression, through its name, that it is mainly concerned with miniaturization concepts, reliability improvements and cost reductions have actually become its main assets.

When the advantages of microelectronic techniques were discovered, the industry moved rapidly to transfer laboratory developments to practical applications. As a result, the electronics industry with its untiring

### MODERN MICROELECTRONICS

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apparatus is available which allows this to be done. All photoresist operations, up to this step, must be performed in yellow red (non-blue) light in order to avoid exposure of the resist. After alignment, the wafer with the mask tightly pressed against its surface is exposed to light with a high ultraviolet content. This changes the polymerization of the resist. The wafers are developed in proprietary developing solutions or xylene and dried. Then the wafers are baked in a vacuum oven in order to harden the remaining resist and improve its acid resistance. This pattern is then etched through the silicon oxide so that a suitable pattern of openings exists through which diffusing impurities will pass. In forming contact or interconnection patterns of metal, it is most common to use a reverse process wherein the unwanted metal is removed from the surface, leaving behind the desired pattern. After the resist is used for the etching operation, it is removed from the surface before subsequent silicon processing. This may be accomplished by heating the wafer in hot sulfuric acid for a short period of time.

The state-of-the-art of photoengraving is such, that it is an inexact science. There is much to learn about all the steps required in obtaining patterns with the desired qualities. At the same time it is apparent that photoengraving techniques have been very successful in both the integrated silicon device technology and in the fabrication of silicon transistors. Photoengraving has been proven far superior to other techniques for obtaining close geometry control in very intricate patterns. The main problems associated with photoengraving, are that the quality of the resist is variable, the optimum processing steps are poorly defined, better resolutions are desirable, mask making is expensive, and surface preparation and printing techniques need further development.

### Diffusion

By diffusing donor and acceptor impurities into semiconductor materials, it is possible to fabricate p-n junction devices that have superior electrical characteristics. The diffusion process has many distinct advantages over other fabrication processes, particularly if silicon is the material used. It is the basic process and in most cases the only process in which superior transistor characteristics can be realized. Junction depths and impurity concentration of the layers can be controlled more precisely than in alloyed structures.

After the introduction of diffusion techniques into semiconductor

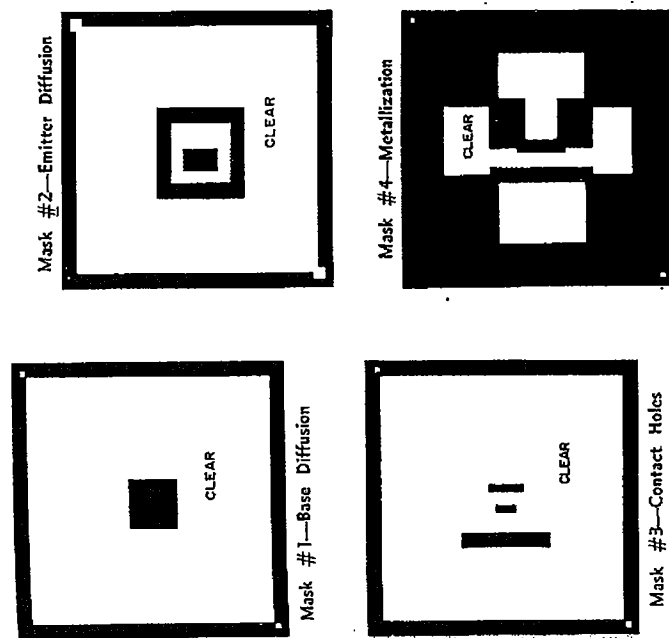


Fig. 9 The lateral dimensions of an IC are set by the photo masks

fabrication, it became possible to achieve base widths, with high accuracy, of less than 1 micron, which improves considerably the transport factor (and therefore  $\alpha$ ) and the transport time (and therefore  $f_{\alpha}$ ). Other means of improving the high-frequency response would be to reduce the collector-base junction area, as has been done with mesa transistors. A typical mesa transistor is shown in Figure 10.

In such a structure, however, the collector-base junction is exposed to the surrounding atmosphere, and surface effects at this point are severe. To minimize surface effects on junctions, the planar diffused structure was introduced. A typical planar structure is shown in Figure 11.

The planar process permits the passivation of the surface by an oxide layer at an early fabrication stage. The silicon-oxide coating is grown on

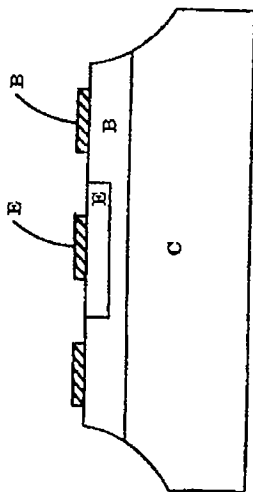


Fig. 10 Mesa transistor

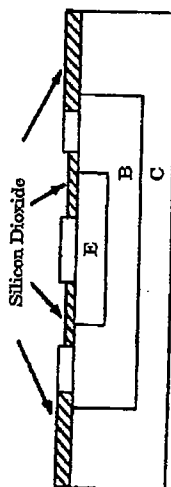


Fig. 11 Planar Structure

the surface before any junctions are diffused. This greatly improves the parameters that are particularly sensitive to surface conditions. These parameters are the reverse leakage currents, breakdown voltages, noise figure, and low-current  $\beta$ . Planar structures, also made it possible to solve many problems in the realization of integrated structures, in which several elements are built simultaneously on the same piece of semiconductor.

Impurity diffusion is another one of the basic tools of silicon integrated device technology. While mathematical theories describing simple kinds of diffusion are known, the diffusions are performed on the basis of empirically determined methods. As with photoengraving, wide variations may be found in the details of the diffusion processes used in practice. These variations include the use of different types of impurity sources, different

diffusion procedures, and different degrees of control. The basic process requires a suitable impurity (dopant) source, almost always either a phosphorus or boron compound. The dopant is transported in vapor form by a carrier gas, usually nitrogen, over the silicon wafers, and then discharged. The entire system is contained in a glass or quartz tubing depending on the temperature. The silicon wafers rest on a quartz boat at a thermally flat region of the furnace which is held very precisely at a specified temperature. Diffusion temperatures range from 900° C to 1200° C. Typical impurity sources for phosphorus are phosphorus pentoxide, phosphorus oxychloride, red phosphorus, ammonium phosphate, phosphorus tribromide, and phosphine. For boron, typical impurity sources are boric acid, boron tribromide, methyl borate, boron trichloride, and diborane. The liquid sources, phosphorus oxychloride and boron tribromide, are the most common. There is some evidence that the gas sources, phosphine ( $\text{PH}_3$ ) and diborane can be used to more advantage.

By following any of the prescribed processes, acceptable diffusion results can be obtained. Normally the diffusion parameters are varied by changing the temperature of the furnace. As silicon integrated device technology becomes more sophisticated, a higher degree of control, than is now possible, will probably be required. Some of the inadequacies which exist in diffusion technology are: (1) agreement between theory and practice is difficult to obtain, (2) data describing diffusion processes vary a great deal between laboratories due to the use of different models, and (3) present diffusion operations are largely empirical and many of the second order effects are not understood.

Thus, the present techniques of diffusion are sufficiently well developed so as to present no problem for most contemporary silicon integrated devices. However, better control and understanding is desirable in order to make devices which are more exactly alike, and whose characteristics can be predicted more accurately.

### Oxidation

The ability of the thermally grown oxide on the surface of the silicon wafer to mask against impurity diffusions and to protect the junction from the environment, is very important in silicon integrated device technology. The requirements for the oxide in the silicon integrated device structure are based on the following conditions:

1. It is first used as a diffusion mask, and becomes thereby inherently contaminated with impurity (dopant).